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DEVELOPMENT OF HOLTER ECG

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MASTER'S THESIS

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APPROVAL AND ACCEPTANCE

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Serife Cansu UYMAZ

TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

°C : Celcius

µm : micrometer

2019nCoV : 2019 Novel Coronavirus

ADC : Analog to Digital Converter

Ag/AgCl : Silver / Silver Chloride

AV : Atrioventricular

aVF : Augmented Vector Foot

aVL : Augmented Vector Left

aVR : Augmented Vector Right

AWS : Amazon Web Services

Ca-Na : Calsium-Sodium

CDC : Center for Disease Control

cm : centimeter

CO2 : Carbondioxide

ECG : Electrocardiography

EEG : Electroencephalogram

GPRS : General Packet Radio Service

GSM : Global system for mobile communications

H+ : Hydrogen ion

HTTP : Hyper Text Transfer Protocol

Hz : Hertz

IEEE : Institute of Electrical and Electronics Engineers

IOS	: Internetwork Operating System
IoT	: Internet of Things
kg	: kilogram
LED	: Light Emitting Diode
LGA	: Land Grid Array
m/s	: meter /second
MCU	: Micro Controller Unit
mm	: millimeter
mmHg	: Millimeters Of Mercury
MQTT	: Message Queue Telemetry Transport
Mv	: millivolt
MΩ	: Megaohm
OLED	: Organic Light Emitting Diode
PCB	: Printed Circuit Board
PDA	: Personal Digital Assistant
PHEIC	: Public Health Emergencies of International Concern
PWM	: Pulse-Width Modulation
RF	: Radio Frequency
RFI	: Radio Frequency Interference
SA	: Sinoatrial
SARS	: Sharp Acute Respiratory Syndrome
Sec	: second
SMS	: Short Message Service
SO_4^{2-}	: Sulphate
SRAM	: Static Random Access Memory
TCP/IP	: Transmission Control Protocol / Internet Protocol

WHO **:** World Health Organization

WMTS **:** Wireless Medical Telemetry Service

Zn **:** Zinc

μA **:** Microampere

LIST OF FIGURES

LIST OF TABLES

ÖZET

HOLTER EKG'NİN GELİŞTİRİLMESİ

Uymaz Ş.C., Aydın Adnan Menderes Üniversitesi, Fen Bilimleri Enstitüsü, Makine Mühendisliği Programı, Yüksek Lisans Tezi, Aydın, 2022.

Amaç: Çalışmanın amacı Covid19 pandemi dönemiyle beraber doktor takibinde olması gereken hastaların uzaktan takip edilmesini sağlayan, riskli durumlarda doktora SMS atan ve hasta verilerini depolayabilen ekonomik ve ergonomik bir Holter EKG tasarlamaktır.

Materyal ve Yöntem: Bu çalışmada 55x84 mm boyutlarında PCB elektronik devre tasarlanmıştır. Hastadan elektrodlar aracılığıyla alınan sinyaller AD8232 EKG sensörü yardımıyla algılanıp, sistemin işlemcisi olan ESP32'ye iletilmiştir. Algılanan verilerin aktarımı için wifi ya da bluetootha ihtiyaç duyulmaktadır. Bu sistemde veriler bir iclouda aktarılacağı için UG96 GSM modülünün wifi özelliğinden yararlanılmıştır. Wifi aracılığıyla veriler UBIDOTSa aktarılır. Aynı zamanda belirlenen kişilere acil durumda SMS atılır.

Bulgular: PCB devre tasarlandıktan sonra elektrodlar bir bireye tek kanallı elektrod yerleşimine göre yerleştirilmiştir. Elektrodlar aracılığıyla algılanan sinyaller mV seviyesindedir ve AD8232 ile bu sinyaller yükseltilir. Yükseltme için gürültü ve parazitler filtrelenir. Algılanan veriler yazılım algoritmasına göre hastanın kalp atışı 10 saniye boyunca 120 bpm ve üzeri ya da 40 bpm ve altında kaydedildiğinde EKG verilerini clouda kaydetmiştir. Aynı zamanda daha önceden hastanın acil durumlar için belirlediği numaraya SMS göndermektedir.

Sonuç: Belirlenen şartlarda verileri kaydetme ve sms gönderme gerçekleştirilmiştir. Depolama, batarya ve işlem hızı düşünülerek veriler 24 saat değil sadece belirlenen koşullar gerçekleştiğinde kaydedilmektedir. Depolanan verilere ubidots aracılığıyla ulaşılır. Tasarlanan system 2 kadın ve 1 erkek olmak üzere 18 yaş üstü 3 bireyde test edilmiştir. Gürültüyü minimuma indirmek ve daha iyi sonuç almak için elektrodlara jel sürülmüştür. Üç bireyde de benzer EKG grafikleri elde edilmiştir.

Anahtar Kelimeler: Covid19, Holter EKG, Uzaktan takip.

ABSTRACT

DEVELOPMENT OF HOLTER ECG

Uymaz S.C., Adnan Menderes University, Graduate School of Natural and Applied Science, Department of Mechanical Engineering, Master's Thesis, Aydin, 2022.

Objective: The aim of the study is to design an economical and ergonomic Holter ECG that enables remote follow-up of patients who need to be followed by a doctor with the Covid19 pandemic period, and sends e-mails and SMS to the doctor in risky situations.

Materials and Methods: In this study, a 55x84 mm PCB electronic circuit was designed. The signals received from the patient through the electrodes were detected with the help of the AD8232 ECG sensor and transmitted to the ESP32, the processor of the system. Wi-Fi or Bluetooth is needed for the transfer of detected data. In this system, since the data will be transferred to an iCloud, the wifi feature of the UG96 GSM module was used. Data is transferred to UBIDOTs via wifi. At the same time, SMS is sent to the designated people in case of emergency.

Results: After the PCB circuit was designed, the electrodes were placed on an individual according to a single-channel electrode layout. The signals detected through the electrodes are in the mV level and these signals are amplified with the AD8232. Noise and interference are filtered out for amplification. The detected data recorded the ECG data to the cloud when the patient's heartbeat was recorded at 120 bpm or above or 40 bpm and below for 10 seconds according to the software algorithm. At the same time, it sends an SMS to the number previously determined by the patient for emergencies.

Conclusion: Saving data and sending SMS were carried out under the specified conditions. Considering the storage, battery and processing speed, the data is recorded only when the specified conditions are met, not 24 hours. The stored data is accessed via ubidots. The designed system was tested on 3 individuals, 2 women and 1 man, over the age of 18. Gel is applied to the electrodes to minimize noise and get better results. Similar ECG charts were obtained in all three individuals.

Key Words: Covid19, Holter ECG, Remote monitoring.

1. INTRODUCTION

Diseases related to the heart and circulatory system have increased significantly in recent years. Worldwide, heart and circulatory system diseases are at the top of death statistics. According to the data of the World Health Organization, The cause of 16% of total deaths worldwide is ischemic heart disease. In 2019, 8.9 million people died because of this.

As stated by the World Health Organization, the global causes of death can be listed as follows (World Health Organization, 2020).

Table 1.1. The global causes of death in 2019 (World Health Organization, 2020).

No	Diseases	Death Statistics
1	Cardiovascular Diseases	>8.5 million
2	Stroke	>5 million
3	Chronic obstructive pulmonary disease	>3 million

The World Health Organization has stated that 80% of early heart disease and stroke are preventable. In this case, early intervention is important.

On the other hand, the whole world has been struggling with the Covid 19 pandemic for two years. Covid 19 (New Coronavirus Infection) is a viral infection that makes a pandemic and spreads very quickly all over the world and in our country. The first case of coronavirus disease 2019 (COVID-19) was emerged on on December 8, 2019 in Wuhan, Hubei Province, China. Epidemic rapidly spread to other parts of China and overseas. In the early stage, most of these patients reported a history of contact with Wuhan seafood (Huang et al., 2020, Chen et al., 2020, Wang et al., 2020). There after, more and more patients developed symptoms of fever and cough. On January 7, 2020, a new coronavirus was detected in a patient's throat swab sample by the Chinese Center for Disease Control and Prevention (CDC) and was later named 2019nCoV by the World Health Organization (WHO) (Huang et al., 2020, Chen et al., 2020).

As the case worsened, WHO declared the outbreak a public health emergency of international concern (PHEIC) (Zarocostas, 2020). The International Committee on Virus Taxonomy renamed the virus sharp acute respiratory syndrome coronavirus 2 (SARS CoV 2), on February 11, 2020.

The World Health Organization declared the epidemic disease caused by SARS CoV 2 as coronavirus disease 2019 (COVID 19). It has been declared as a Pandemic by WHO. As of October 23, 2021, a total of 244,026,558 cases have been approved globally, resulting in 4,957,779 deaths (Anonymous, 2021a.). The most usual symptoms in Covid-19 are shortness of breath, fever, cough and myalgia (Huang et al., 2020). Hypotension, cardiac arrhythmias and even sudden cardiac death may appear as symptoms of Covid-19 (Xiong, 2020).

The disease progresses more severely in people who smoke, are over 50 years old, and have diseases such as diabetes, chronic lung diseases, cardiovascular diseases, and cancer (Rod et al., 2020). Although lung involvement is prominent in the course of the disease, many studies have shown that Covid-19 infection causes cardiovascular disorders, which may be an important factor in disease-related mortality (Long et al., 2020). Studies have reported that Covid-19 is associated with acute myocardial damage, and it has been found that it may cause an increase in the risk of acute myocarditis, ventricular arrhythmia, acute coronary syndrome and heart failure (Kochi et al., 2020).

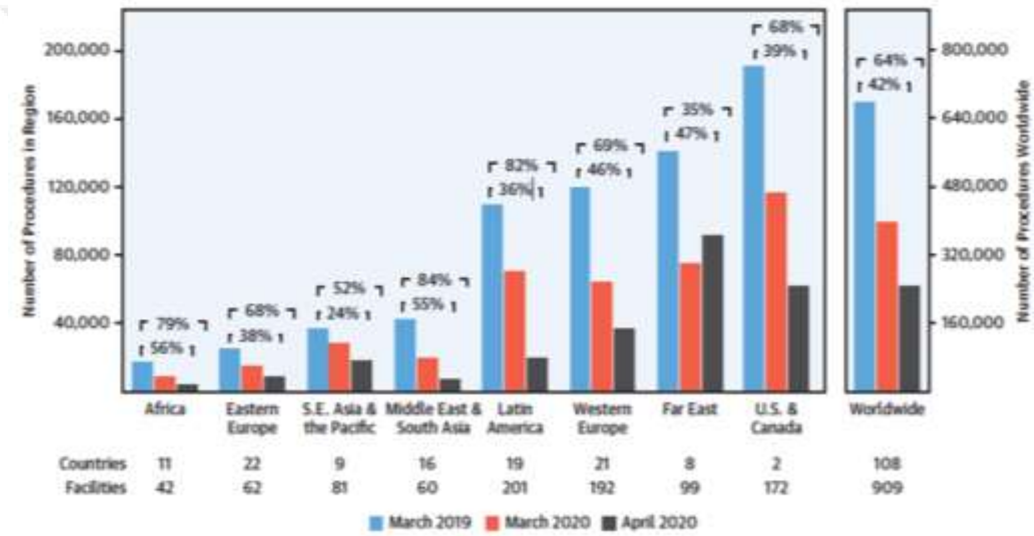
Electrocardiogram (ECG) is designed to examine the heart activity of patients. The primary purpose of the ECG is to obtain the patient's ECG information. Thus, people's heart disease can be investigated in more detail. ECG plays an significant role in the detection of cardiovascular diseases like cardia arrhythmias, myocardial ischemia, myocardial infarction. However, the traditional ECG device is expensive, large and restricts the patient's mobility, preventing the patient from getting out of bed.

Due to the pandemic, curfews were imposed, and people did not want to go to the hospital, except for emergency and serious situations. For these reasons, the Corona virus pandemic has detrimentally affected the diagnosis and treatment of non-communicable diseases. Doctors may want to follow their patients without having to hospitalize them. However, it is not convenient for every individual with cardiovascular disease to purchase an ECG device, both economically and ergonomically. Because these devices are both expensive and not suitable for use in daily life.

In addition, the interpretation of signals requires technical knowledge. All of this has led to the need for an affordable and portable ECG that can transmit the recorded information to the patient's doctor.

The table below shows data for March 2019, March 2020 and April 2020.

Table 1.2. Decrease in worldwide cardiovascular disease diagnostic testing volume in the initiation of the coronavirus disease 2019 pandemic (March and April 2020) (Einstein et al., 2021).



1.1. Historical Development of Electrocardiography

After the existence of electricity was discovered in the 17th and 18th centuries, the effects of electricity on animal tissue were found. In the 19th century, sensitive devices that could recognize tiny electrical currents in the heart were designed. The first precise recording of the electrocardiogram was taken at the beginning of the 20th century, and to this day, the electrocardiography device is still being developed as a clinical tool (Anonymous, 2022a).

The Dutchman Jan Swammerdam saw that after removing the heart of a live frog in 1664, the animal could still swim, and all movement stopped when its brain was removed.

But he observed that the muscles attached to the animal twitched when the split nerve ending was stimulated with a scalpel after the animal was dismembered.

These events demonstrated that muscles can move without any connection to the brain (Anonymous, 2022b).

In 1668, Swammerdam put a frog's thigh muscle in a glass tube. By stimulating the nerve connected to the muscle that he removed through a hole in this tube, he caused the muscle to contract and saw that the muscle volume increased (Figure 1.1).

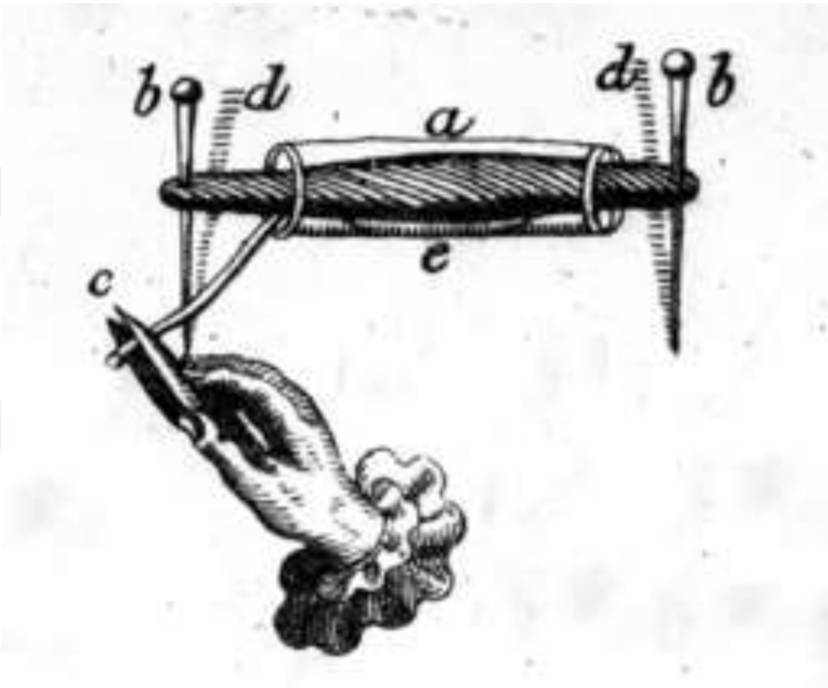


Figure 1.1. A neuromuscular assembly of Swammerdam. the glass tube, (b) the muscle, and (c) the nerve (Anonymous, 2022c).

In 1786, Italian anatomist Luigi Galvani observed that when he was near an electrical generator and touched the nerves in the leg of a split frog with a scalpel, all the muscles contracted in succession.

Later, he determined that the heart muscle contracted with the electrical stimulus in the frog's heart. The name of the galvanometer, which measures and records electricity, comes from Galvani.

In 1792, Italian scientist and inventor Alessandro Volta attempted to refute the "animal electricity" approach by showing that electric current is produced when two dissimilar metals come into contact with each other. He argued that the electric current came from metals, not animal tissues, and he tried to prove it in 1800. He developed the first electrochemical battery (Anonymous, 2022d). This battery contained two electrode rods, one zinc and the other copper. Sulfuric acid or salt water was used as the electrolyte. The electrolyte is in the form of 2 H^+ and SO_4^{2-}. Zinc is extra positively charged than copper and hydrogen. Therefore, zinc reacts with negatively charged sulfate SO_4^{2-}. Positively charged hydrogen balloons begin to accumulate around the copper electrode.

Figure 1.2. First electrochemical battery

It starts and gains some of its electrons. This makes the zinc rod the negative electrode and the copper rod the positive electrode. H; Hydrogen, Zn; Zinc, to-; is electron. Copper, which acts as an electrode, does not react (Anonymous, 2022e).

The electrical activity of the heart was first demonstrated by Kölliker and J. Müller (1856). Dutch physiologist Einthoven recorded cardiac action currents with his own galvanometer (1903). He won the Nobel Prize in Medicine for this invention (1924). This first device developed weighed 270 kg.

As the electrocardiography device was developed, it got smaller. Today, the weight of hand-held ECG devices is under 1 kg. Further unique recording devices are also available. The working notion of these devices are also like those of Einthoven's first device. Newly, computers have also entered this field. It is also feasible to record and view the ECG on paper at the same time. There are also devices that instantly evaluate and report the obtained data (Anonymous, 2022f).

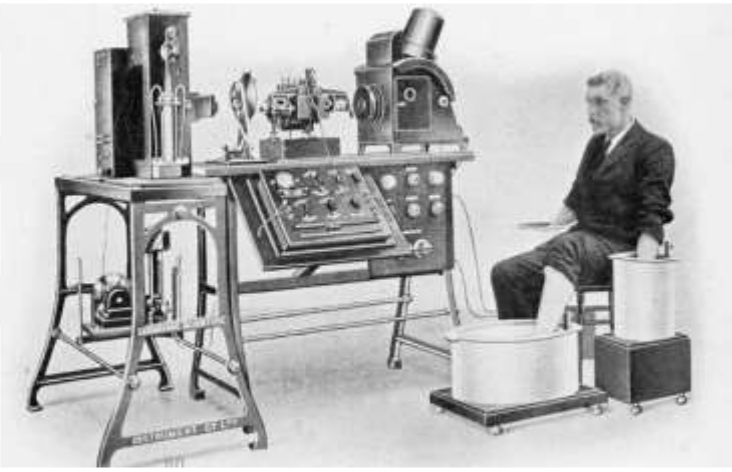


Figure 1.3. First Electrocardiogram (Anonymous, 2022g).

1.2. Purpose

The aim of this project is to ensure that patients at risk are under the control of a doctor remotely with portable ECG without the need to stay in the hospital, and to inform the doctors and patient relatives via e-mail and SMS in possible emergencies.

In addition, some scientific studies have been conducted to show that the ECG findings of patients with covid disease and those who use drugs in their treatment are different from healthy individuals. Thanks to the system's recording of ECG findings of patients at critical moments, it is aimed to guide and contribute to scientific studies in order to shed light on the effects of drug users on ECG findings during or after covid.

2. LITERATURE REVIEW

2.1. Circulatory System Overview

The circulatory system is a system made up of the heart and blood vessels. In this system, the heart is positioned in the center, and the vessels form a closed pipe system that go away from the heart and turn back to the heart. The vitality of organs and tissues can only be achieved by transmitting the nutrients they need to the smallest living unit in the human body, the cells. In addition, such an important system has been created in the units related to the delivery of oxygen, for tasks such as oxidation, removal of CO2 and metabolism residues, distribution of enzymes, vitamins and hormones in the body, as well as providing body temperature. In this regard, the circulatory system; It is an extremely important organization for nutrition, respiration, metabolism, transport, regulation and body defense. Here, the means of transport is blood, and the road is blood vessels.

After all this, a functional division of the circulatory system should be carried out. Because here, there is a need for a formation that allows the blood to be sent from the center to the periphery, and a closed system during this process of the blood going all the way to the periphery. Here, the center of movement is the heart, and the blood's conduction pathways are seen as vessels whose functional classification is very different.

Blood vessels are generally classified as arteries (arteries) that ensure the transmission of oxygen-rich blood to the thinnest capillaries (capillaries) and have higher pressure in them, and veins (veins) that bring oxygen-poor blood to the center (heart) that have completed their function. The motor organ of blood circulation is the heart (Alptekin, 2010).

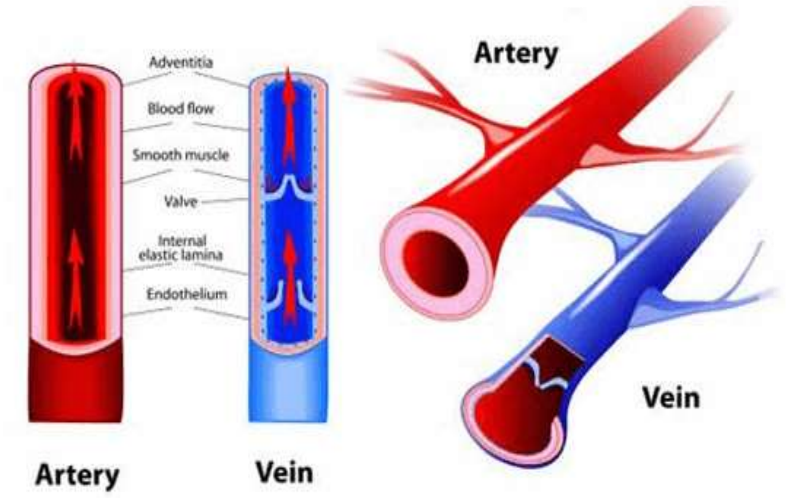


Figure 2.1. Artery and vein (Anonymous, 2022h).

The heart consists of two semi-pumps, as shown in Figure 2.2 : the right heart, which pumps blood to the lungs, and the left heart, which pumps blood to the surrounding organs. Each of these hearts is a two-chamber pulsating pump consisting of an atrium and a ventricle. The main function of the atria is to help carry blood to the ventricles. The ventricles, on the other hand, provide the main pumping force that provides the large blood circulation and the small blood circulation (Guyton and Hall, 2007).

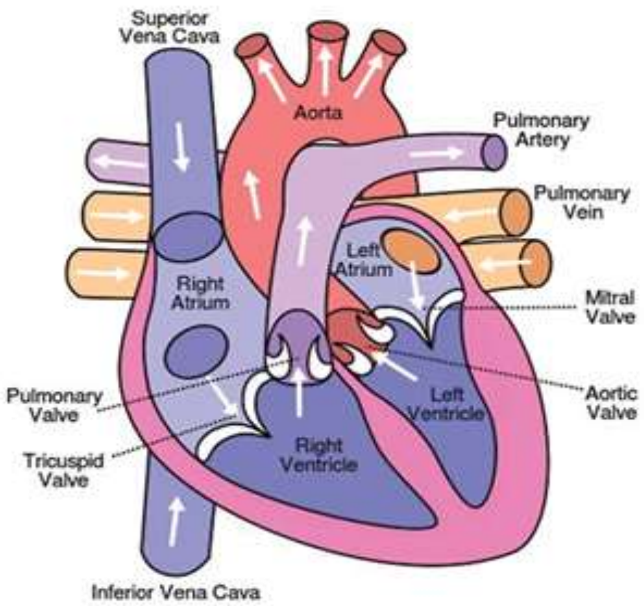


Figure 2.2. The parts of heart (Anonymous, 2022i).

2.2. Circulatory System and Heart Anatomy

The heart is positioned in the thoracic cavity between the lungs, in the mediastinum (center of the thorax). About two-thirds of it lies to the left of the middle sagittal line (median plane). The superior part of the heart, where the great vessels connect, is called the "base". The lower end of the heart, which is inclined to the left and gradually tapering, is called the "hill". Dimensions of an adult heart; It is almost 9 cm wide at the base, 13 cm from the base to the apex, and approximately 6 cm from anterior to posterior at its thickest point. Its weight is about 300 gram (Guyton and Hall, 2007).

The right and left parts of the heart are completely apart from each other by a wall (Septum). The heart in mammals has a four-chambered structure consisting of atria and ventricles. The heart pumps about 9000 liters of blood a day, beating at an ordinary rate of 60 to 80 pulses per minute (Ekmekci, 2017).

The heart, which begins to beat approximately in the fourth week of pregnancy, beats an average of 100000 times a day in an adult and healthy individual. The heart, which beats two and a half billion times in a 70-year life, pumps blood to whole sections of the body each time (Coskun et al., 2009).

2.2.1. Auricles and Ventricles

Although the heart is a single organ, it consists of two parts that send blood to the lungs and other organs. Each of these two parts consists of one ventricle and atrium. The Right Atrium is connected to the lower and upper veins, and the transported dirty blood returns to the heart from the right atrium. The right ventricle is located below the right atrium and in front of the left ventricle. Dirty blood is sent to the lungs from the right ventricle (Meric, 2007).

Heart chambers called atria and ventricles occur in all normal hearts. These chambers are connected to each other by the valves and the gaps (holes) they close.

According to this division, the right side atrium and ventricle appear as cavities where oxygen-poor venous blood is collected, and the left side atrium and ventricles as cavities where oxygen-enriched blood is stored. In other words, small circulation is provided in the right side spaces and large circulation is provided in the left side spaces.

Superior vena cava opens into the right atrium from above and inferior vena cava from below. With these veins, the oxygen-poor blood that has completed its circulation returns to the heart. In addition, some blood comes to the right atrium through a small pool called the sinus coronarius. A portion of the right atrium extends to surround the aorta, the great vessel of the heart. This is called an auricle (Alptekin, 2010).

Right Atrium: As seen in Figure 1, it is located above the right ventricle and anterior to the left atrium. It is connected to the lower and upper veins. Dirty blood enters the heart from here.

Right Ventricle: As seen in Figure 1, it is located in the lower and left part of the right atrium and anterior to the left ventricle. From here, the dirty blood is sent to the lungs for purification.

Left Atrium: As seen in Figure 1, it is positioned behind the right atrium and above the left ventricle. Oxygenated blood comes to this part of the heart.

Left Ventricular: As seen in Figure 1, it is positioned behind the right ventricle and below the left atrium. Clean blood coming to the left atrium is pumped to other organs from here.

2.2.2. Valves

There are 4 valves in the heart. These are two atrioventricular valves and two great vessel valves (semilunar). These valves are located between the atria and ventricles. Valves are like valves, to prevent the blood from flowing in one direction and to prevent the blood from coming back, otherwise, if the blood comes back, an undesirable event called murmur will occur. The valves allow the blood to enter and exit the ventricles in one direction.

Tricuspid valve: The valve between the right atrium and the right ventricle.

Pulmonary valve: Three half-moon-shaped valves between the right ventricle and the pulmonary artery (lung artery) to prevent the return of the blood pumped from the right ventricle.

Mitral valve: The valve located between the left atrium and the left ventricle.

Aortic valve: They belong to the left ventricle and are located at the mouth of the aortic opening, through which oxygen-rich blood is directed into the great circulation. Very important vessels that leave the aorta at the level of the aortic valves provide the nourishment of the heart. After leaving here, they extend to the relevant regions by wrapping the heart in the form of a crown in both directions.

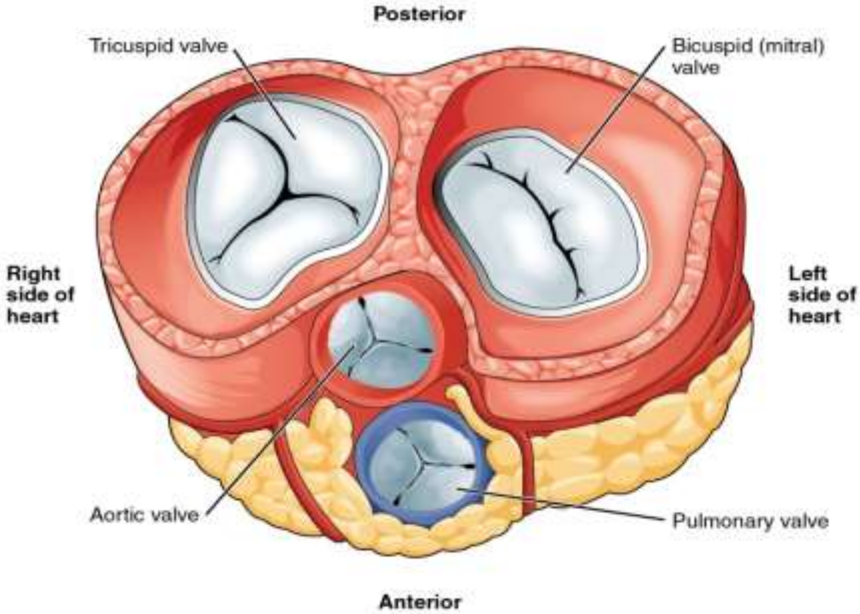


Figure 2.3. Heart valves (Anonymous, 2022j).

The nutrition of the heart is provided through special veins. Nourishing blood comes to the heart through the coronary vessels that separate directly from the aorta at the level of the aortic valves and surround the heart from the right and left as if in a crown.

Despite the presence of connecting branches between these heart-feeding main vessels, myocardial infarction occurs when one of the major vessels suddenly closes.

However, if the narrowing of the vessels occurs with a slow course, a strong situation in collateral vessel development occurs. This situation prevents the acute event (Alptekin, 2010).

The pericardium is a double-walled layer that surrounds the heart. The prefix “Peri-” means environment or surroundings (Saladin, 2003).

The inner and outer surfaces of the walls of the heart (muscle structure) are covered with a shiny, slippery and thin cover (connective tissue layer). The wall of the heart is divided into 3 layers:

• Endocardium (endocardium): The layer that covers the inner cavity. The endocardium is a thin, hollow tissue layer that covers a simple flat endothelium. It forms the smooth inner surface of chambers and valves and is a continuation of the endothelial layer of blood vessels. The prefix “endo-” means “inside” .

• Myocardium: The main muscle layer of the heart. The thickest layer, the myocardium, consists entirely of cardiac muscle and carries out the heartbeat activity .

• Epicardium (epicardium): The layer that encloses the outer surface of the heart. The prefix “epi-” means “on”. The epicardium, that is, the visceral pericardium, is a membrane consisting of a thin and hollow (areolar) tissue layer over the simple squamous epithelium .

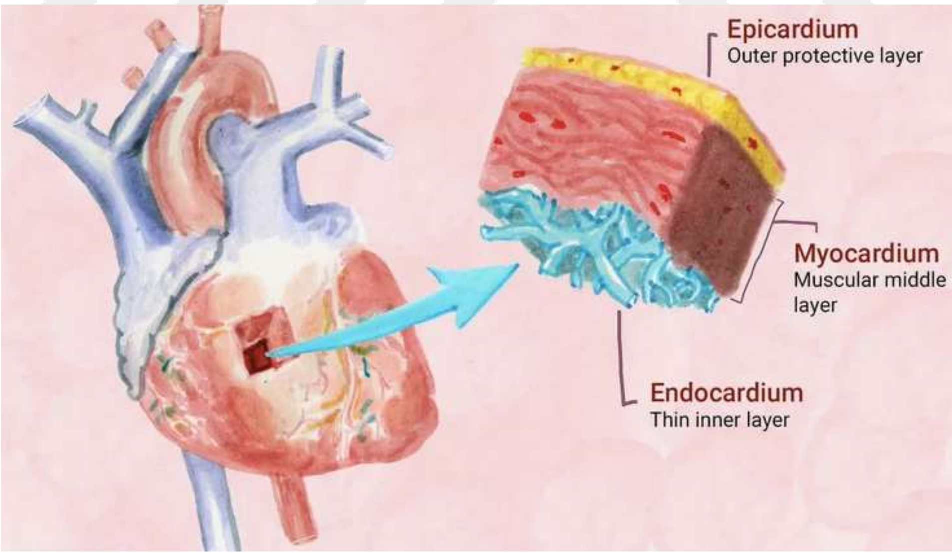


Figure 2.4. The layers of heart wall (Anonymous, 2022k).

2.3. Work of Heart and Heart Physiology

The heart works by contraction (systole) and relaxation (diastole) of the heart muscle. The heart involves of two distinct pumps; The right heart pumps blood to the lungs and the left heart to the peripheral organs (Ekmekci, 2017).

Systole is the time it takes for blood to be pumped into the pulmonary artery and aorta by contraction of the left ventricular muscles. The right and left ventricles simultaneously pump blood to the lungs and aorta.

Diastole is the time during which the heart chambers relax and fill with blood. High blood pressure is named systolic blood pressure and low blood pressure is called diastolic blood pressure.

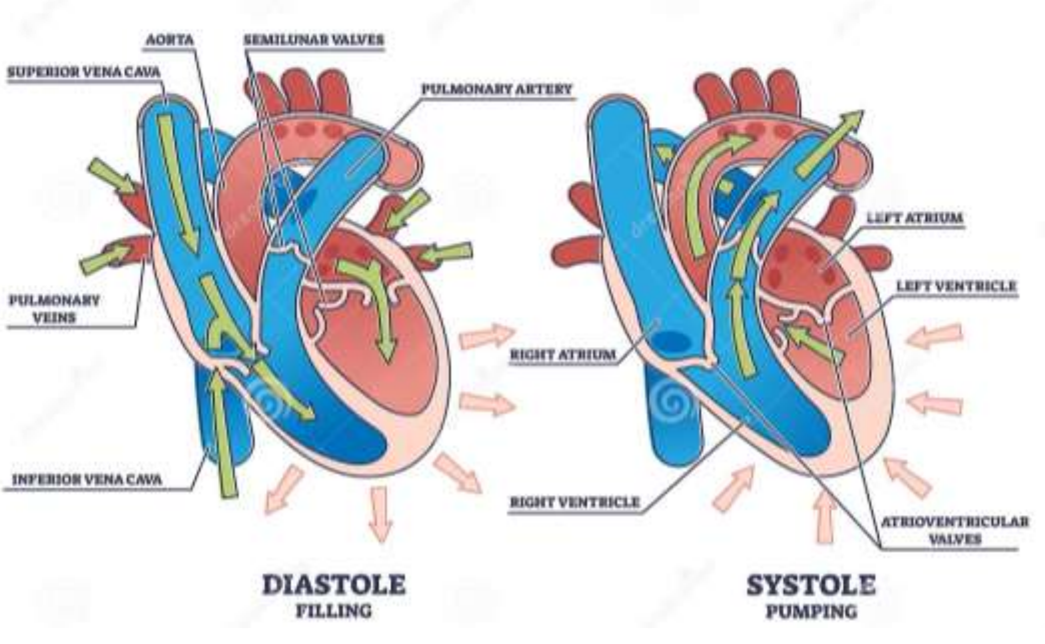


Figure 2.5. Diastole and Systole (Anonymous, 2022l).

In society, systolic blood pressure is called "High Blood Pressure". Diastolic blood pressure in the community is called "Low Blood Pressure". It is usually shown and spoken as systolic pressure/diastolic pressure.

The unit of measurement for blood pressure is mmHg. In a healthy person, the systolic blood pressure of the blood pressure measured from the artery in the arm is observed between 95 and 130 mmHg.

The ideal systolic blood pressure should be 120 mmHg. Diastolic blood pressure reading from a healthy person is observed in the range of 60 to 90 mmHg. The ideal diastolic blood pressure should be 80 mmHg.

After the blood is pumped into the arteries, the heart goes into a resting state, the exit valves close, after a short period the entry valves open, diastole and a new cardiac cycle begin (Yazgan, and Korürek, 1995).

When the right atrium is full, it contracts, allowing blood to pass into the right ventricle through the tricuspid valve. With the contraction of the right ventricle, the crescent-shaped pulmonary valve opens and blood is pumped into the pulmonary veins. When the pressure in the ventricle increases above the pressure at the atria, the tricuspid valve closes. The pulmonary artery divides into two branches and reaches the lungs. In the lungs, it divides into smaller and smaller branches and divides into capillaries with extremely small cross-sectional areas. Gas exchange in the lungs takes place in air sacs called alveoli. These capillaries feed the capillaries (capillaries) that line the alveoli. On the other hand, the cleaned blood reaches very fine capillaries through these capillaries, and from there, it grows larger and reaches the pulmonary vein and the left heart. The blood entering the left atrium from the vein is pumped to the left ventricle through the mitral valve by contraction of the left atrium muscles. As a result of the pressure created whereas the left ventricle muscles contract, the mitral valve closes. Again, as a result of the increase in pressure in the ventricles, the aortic valve opens and blood is pressed into the aorta. Simultaneously with this event, the pulmonary valve opens and the dirty blood in the right ventricle is pressed into the pulmonary artery (Yazgan and Korürek, 1995).

In summary, the dirty blood that circulates throughout the body and gives oxygen turns back to the right heart and is pumped to the lungs. Here, the blood cleaned by getting plenty of oxygen is transferred to the left heart; With the contraction of the left heart, it is pumped into the arterial system to circulate the whole body (Okyar, 2006).

2.3.1. Electrical Activity of the Heart, Regulation of Rhythmic Contraction

Excitable tissues demonstrate the capacity to generate and transfer action potentials by changing the electrical features of cell membranes against any stimulus. Nerve and muscle tissue are excitable tissues. There are two sort of potentials in cell membranes, resting and action potentials. While the resting potential is a potential that occurs with the placement of ions in different distributions inside and outside the cell when the cells are not doing any work, the action potential is a series of potential changes that occur in the membrane as a consequence of the movement of some ions into and out of the cell while the cells are active. Excitable tissues form the action potential and transmit the electrical activity that arises with this potential change across their membranes (Alptekin, 2010).

In the heart muscle, the action potential occurs with the opening of two sort of channels; same and fast Na channels and completely different and slow Ca channels. These are also called Ca-Na channels. Ca channels differ from fast Na channels in that they open more slowly and remain open for a short time. In the meantime, a vast number of calcium and sodium pass by these channels and enter the heart muscle. This provides a long-term depolarization, so that a plateau occurs in the action potential. In addition, the calcium ions that come in during this plateau activate the muscle contraction process.

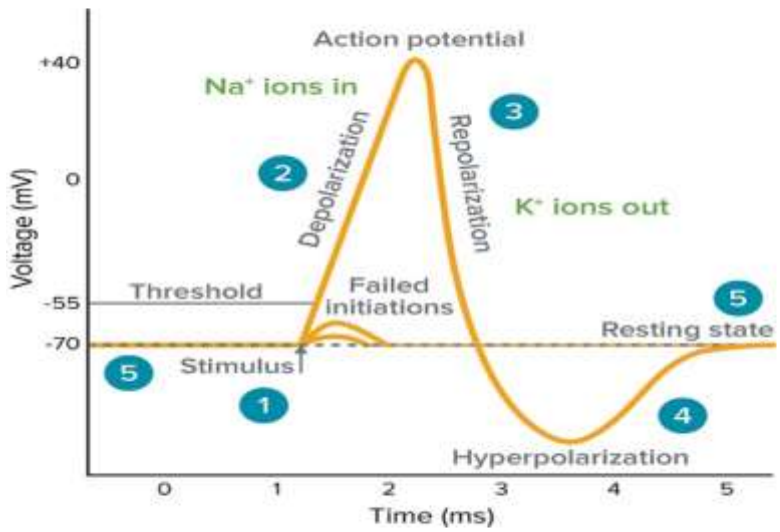


Figure 2.6. Action potential (Anonymous, 2022m).

Shortly after the onset of the action potential, the potassium ion permeability of the cardiac muscle membrane falls five times. This decreased potassium ion permeability may be due to the large amount of calcium from the Ca channels. Irrespective of the cause, the decreased potassium permeability also significantly reduces the output of positively charged potassium ions throughout the action potential plateau, thus preventing the action potential from returning to its resting level prematurely. As the slow calcium-sodium channels are closed in 0.2 to 0.3 seconds and the entry of calcium and sodium ions is interrupted, the potassium ion permeability of the membrane suddenly rises. This sudden loss of potassium from the tissue immediately reduces the membrane potential to its resting level. As a result, the action potential is terminated.

In atrial and ventricular muscle tissues, the conduction velocity of the action potential warning signal is between 0.3 and 0.5 m/s. In the unique transmission system of the heart - Purkinje fibers, the speed is as high as 4 m/s in most of the system. This speed is quite proper for transmitting the warning signal to different parts of the heart (Özcan, 2010).

The heart is a versatile organ that constantly generates a certain electrical potential and then performs a mechanical work such as contraction. Therefore, the heart can be considered as an electromotive force source (Erbil, 2007). Figure 4 shows the electrical signals generated in consequence of the physical movement of the heart.

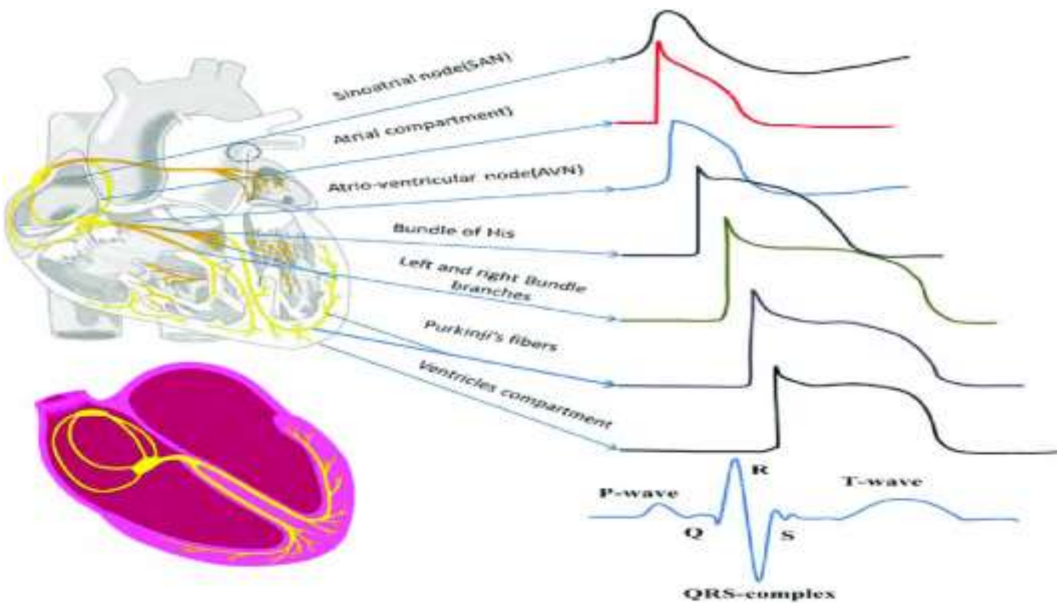


Figure 2.7. Electrical Signals Generated by Heart Movements (Abbas, 2009).

2.3.2. Heart's Warning and Conduction System

The heart is an organ that has the ability to contract rhythmically without any warning. The heart pumps blood by the pressure created in its chambers. As a result of pumping the blood, the blood pressure flows from the strong side to the weak side in such a way that it cannot return. This created heart pressure causes the heart to contract, and the place where this contraction in the heart begins is the section where the main veins enter the heart. The contraction that starts continues on its way by spreading to the atria and then to the ventricles. During the contraction of the heart, the throwing of the blood coming to it is realized by the contraction and relaxation of the electrical currents occurring in the heart. The value of the electric currents formed as a result of contraction and relaxation is at the level of millivolts (mV). These current values measured at mV level are converted into a form that can be monitored and recorded by increasing their values with special devices (Ekmekci, 2017).

The electrical stimulation and conduction system of the heart consists of four parts. These; (SA), (AV) atrioventricular node, bundle of his and its branches and Purkinje fibers. Of these, the (SA) node and (AV) node are the stimulus, the his bundle and Purkinje fibers are the conduction system (Yazgan and Korürek 1995).

The SA and AV nodes are located in the right atrium. The bundle of His is attached to the AV node and divides into right and left branches in the interventricular compartment. The branches of the bundle of His also enter the ventricles and connect with the Purkinje system (Alptekin, 2010).

The SA node is a tiny, flat, elliptical strip of special cardiac muscle 3 mm in width, 15 mm in length and 1 mm in thickness. The SA node is placed in the upper lateral wall of the right atrium, next to the entrance to the superior vena cava. The tissues of this node have nearly no contractile muscle fibers and each is 3 to 5 µm in diameter. Since the sinusoidal nodal tissues and the atrial muscle tissues are directly connected, a signal that starts here immediately spreads to the atrial muscle wall (Ozcan, 2010).

SA node 70-80 per minute, AV node 40-60, his bundle and Purkinje fibers are capable of generating spontaneous impulses at lower speeds.

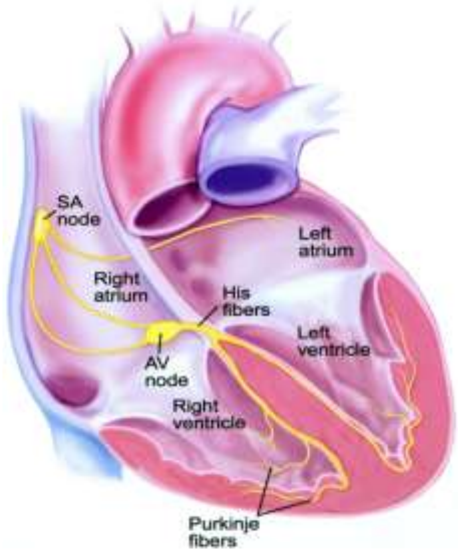


Figure 2.8. The electrical conduction system of the heart (Willerson, 2002).

The heart continues to work functionally due to this conduction system. As a consequence of this contraction of the heart muscles, an electrical signal occurs. This Electrocardiogram sign can be detected from the human body thanks to the ECG device (Ekmekci, 2017).

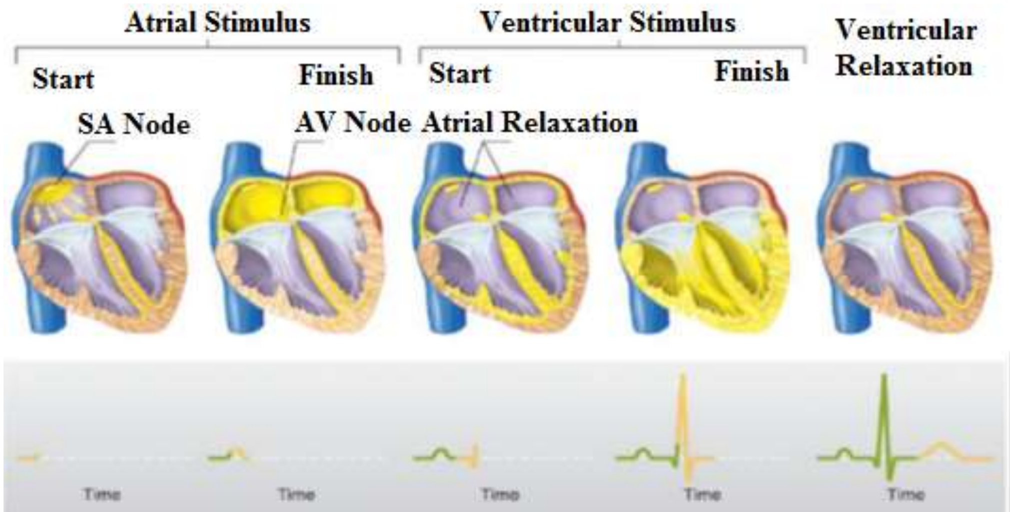


Figure 2.9. Heart conduction system

2.4. Electrocardiography

The signals that occur with the electrical activity during the heart's work and are detected with the help of electrodes from certain parts of the body are called Electrocardiography (ECG).

ECG demonstrates the contraction of the heart muscle, helps to diagnose coronary insufficiency or Myocardial Infarction (MI), allows to detect extension of the heart cavities, evaluates roles of the electronic pacemaker, and effects of some cardiac drugs. It is a measurement system that allows to investigate electrolyte imbalance (especially potassium deficiency or excess) and to receive or record the heart signal, which makes it possible to investigate the effects of non-cardiac diseases on the heart (Morris et al. 2003).

2.4.1. Features of ECG Signals

Figure 1 demonstrates a normal ECG signal consisting of P wave, QRS wave and T wave (Yakut et al., 2014).

The P wave in the figure is the depolarization of the atria, the QRS complex is the depolarization of the ventricles, and the T wave is the waves resulting from the repolarization of the ventricles.

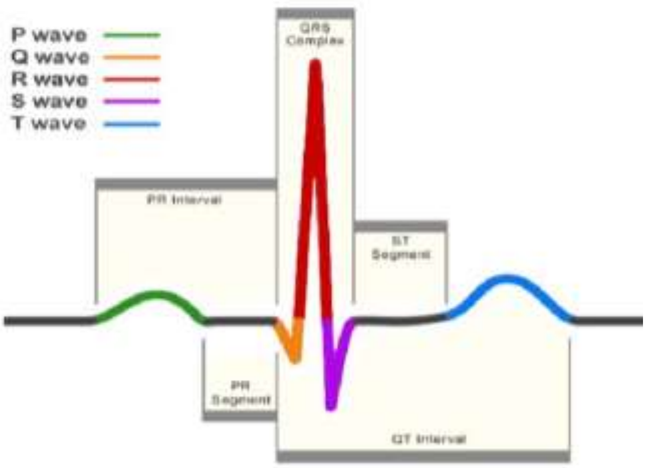


Figure 2.10. ECG signal (Altay and Kremlev, 2018).

A classic ECG detector should have the following features (Kahveci, 2005).

• It should be capable of detecting low amplitude signals in the range of 0.05mV – 10mV.

• It must have a very high input impedance.

• Must have very low input leakage current.

• It should have a flat frequency response of 0.02 Hz – 150 Hz.

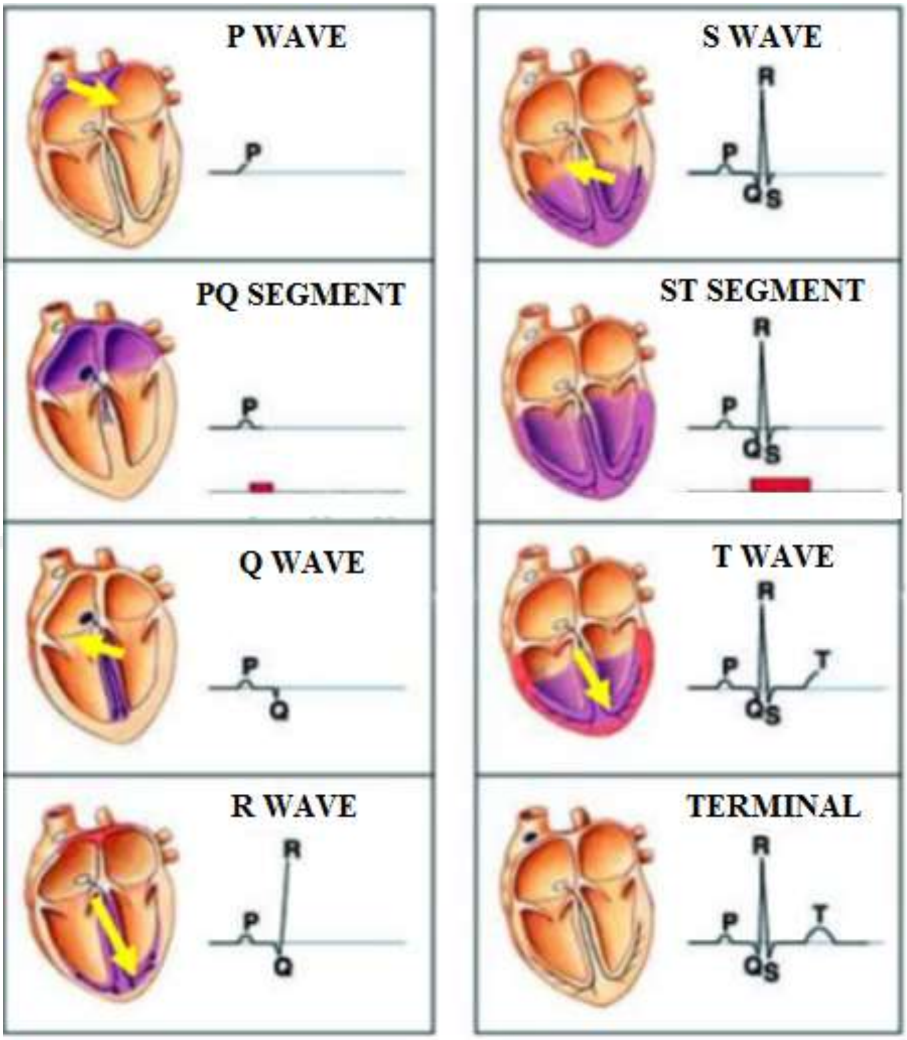


Figure 2.11. ECG sign formation (Canan, 2014).

The ECG sign is defined as the electrical signals created by the heart in the form of a P – QRS – T wave sequence. The small U wave is usually not visible. There are cardiac cycles in the ECG. These expressions express the starting and ending points of the waves that make up the ECG signal.

The horizontal straight line between two heart cycles is called the isoelectric line (baseline). The phenomenon that the waves in the ECG signal stay above or below the isoelectric line is called deflection.

This situation changes with the direction of the electrical current and becomes negative if it is below the baseline and positive if it is above the baseline.

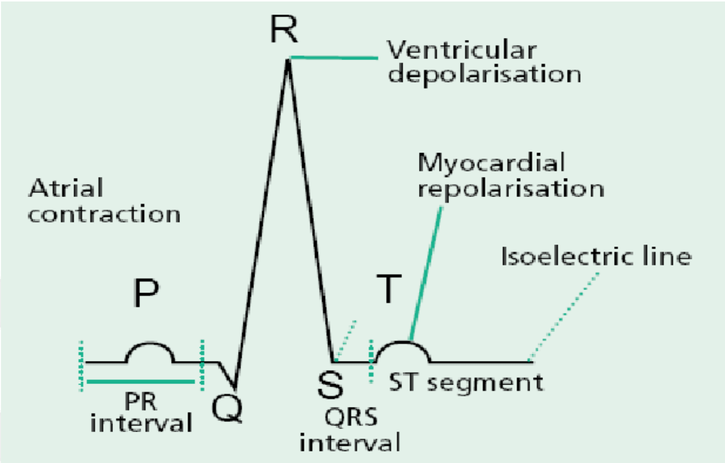


Figure 2.12. PQRST Waves

The P wave is created by the electrical potentials generated during the depolarization of the atria earlier they begin to contract (Figure 2.12). The QRS wave is depolarization waves, which are the components of the wave that causes the ventricles to depolarize earlier contraction, that is, during the propagation of the depolarization wave throughout the ventricles (Guyton and Hall, 2007).

The QRS wave determines the time from the beginning of the Q wave to the end of the S wave. QRS wave occurs in the case of depolarization of the ventricles. Often, if not always, it is the largest wave of the electrocardiogram. It is easy to recognize the examples presented in different derivations of the same ECG as it shows clearly defined forms (Soydan and Terek, 1992).

The T wave is produced by electrical signals formed by the end of the depolarization state of the ventricles. This event normally occurs 0.25-0.35 seconds afterward depolarization in the ventricle, this wave is known as the repolarization wave (Guyton and Hall, 2007).

U wave is not seen all the time. It is tiny and closely follows the T wave. It is thought to indicate repolarization of the papillary muscles or Purkinje fibers.

Notable U waves are common in hypokalemia, but T waves are also seen in hypercalcemia, thyrotoxicosis or digitalis, epinephrine elicitation and Class 1A and 3 antiarrhythmics, those with congenital long QT syndrome, and intracranial hemorrhages.

An reversed U wave indicates myocardial ischemia or left ventricular volume overgrowth (Kurban, 2006).

Table 2.1. Sources of ECG signal

ECG SIGNAL	**SOURCES OF ECG SIGNAL**
P Wave	Atrial Contraction
QRS Complex	Atrium repolarization + ventricular depolarization
T Wave	Ventricular Repolarization
P-Q Wave	Warning time delay

Table 2.2. Average duration of periods (Kurban, 2006).

WAVES	**TIMES**
P Wave	0.08-0.10 sec.
P-R	0.12-.0.20 sec.
QRS	0.06-0.10 sec.
Q-T	<0.44 sec.

The measured signals can be recorded on paper strips, a magnetic tape or electronic memory. Here, the paper on which the ECG signal is recorded is of special quality. In the ECG paper, the horizontal axis contains the data about the time and the vertical axis contains the voltage value. On the horizontal axis, the small square of 1 mm indicates the time of 0.04 s, and the large square of 5 mm with a thick line indicates the time of 0.20 s. On the vertical axis, the 1 mm small square represents 0.1 mV electric current, and the two large 10 mm squares represent 1 mV electric current.

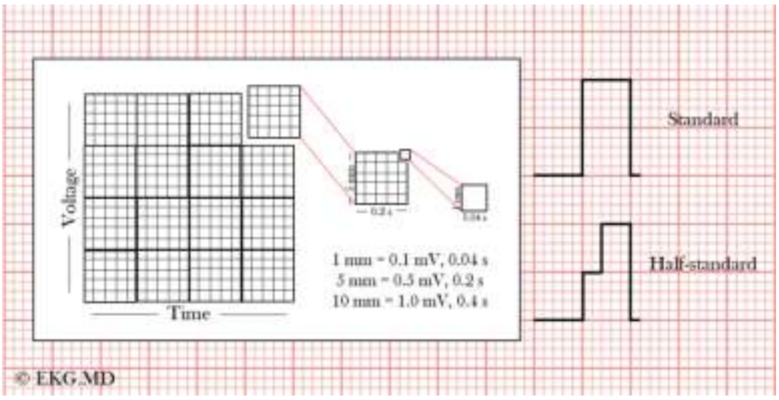


Figure 2.13. The paper on which the ECG signal is recorded and its properties (Anonymous, 2022n).

2.4.2. Electrodes Type of ECG

Electrodes are generally used for sensing electrical biological signals in living organisms. One of these electrical signals for the heart is derived from ECG measurements. ECG measurements are perhaps one of the very ordinary measurements in the field of signal monitoring. ECG electrodes are transducers developed to detect the electrical activities of the heart and to obtain information about the heart from the signals obtained in this way. The electrodes are connected to the human body based on various measuring points. Physicians can take ECG signals from some different points on the body, depending on the need.

ECG electrodes are usually manufactured as Ag/AgCl electrodes. The main reasons for choosing Ag/AgCl are the absence of harmful effects on the human body, its stable behavior, and the reliability of the measurement results. These electrodes are in the class of surface electrodes. Because the obtained signs are perceived from the skin surface. It is produced sometimes as gel-impregnated or sometimes dry, depending on the need. There are types produced in different types and sizes for adults, different for children or babies. There are also ones that can be used once and thrown away and used repeatedly (Can, 2010).

Electrodes used in ECG measurement should have the following features.

• Input impedance must be high> 5 MΩ

• It should be able to detect signals with very low amplitudes (0.05-10mV)

• The input attenuation current should be small< 1μA

• Ability to read signals in the range of 0.05-100 Hz

• CMRR should be high

The most used electrodes are disposable Ag/AgCI electrodes. The biggest reason for the use of Ag/AgCI electrodes is that they do not cause any harm or side effects to the human body and that they are stable and reliable measurements are made. There are different types and sizes of Ag/AgCl electrodes for adults and different for children or infants. In addition to disposable ones, there are also ones that can be used repeatedly. Depending on the physician's request, measurements are made with these electrodes.

2.4.2.1. Surface Electrodes

It is a type of electrode that is placed on the skin surface and used to detect bioelectric signals. While it is generally used in ECG, EEG and bedside monitors, some types of surface electrodes use electrogels on the body surface to maintain conduction stability. Such electrodes are placed one by one on the relevant part of the patient's body and connected to the electrocardiogram with the electrode cable. The most important advantages of these electrodes are that they reduce the possibility of error in finding the relevant region and save time.

2.4.2.2. Disposable ECG Electrodes

These electrodes are widely used in ECG measurements and are discarded after being used once. This type of electrode is demonstrated in Figure 2.14. The electrolyte is carried out just below the Ag-AgCl electrode base, as a gel, impregnated sponge, adhered to the electrode.

The biggest advantage of these electrodes is that there is no need for cleaning as they are thrown away after use and there is no hygienic contamination from one person to another. The downside is that it is disposable.

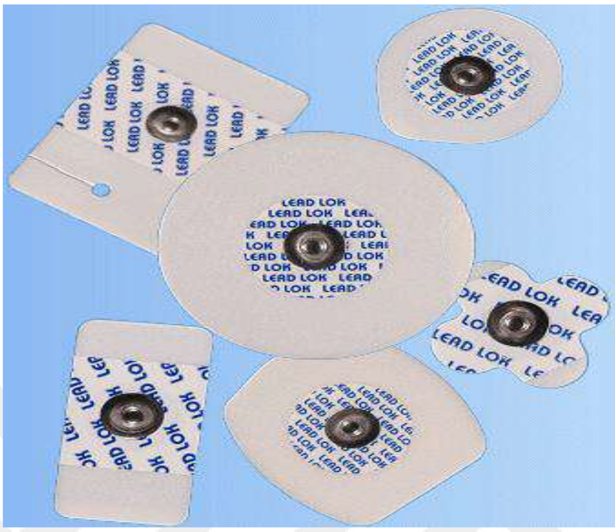


Figure 2.14. Disposable ECG electrodes

2.4.2.3. Flexible ECG Electrodes

Such an ECG electrode can bend and flex to take the shape of an uneven body surface. The most used type is the one in the form of an adhesive tape, one side of which is partially knitted with silver (Ag) wires.

There are those that are flexible that will not affect or restrict the patient's daily movements. These electrodes have types used under clothing as well as types used by attaching to clothing. These are also disposable.

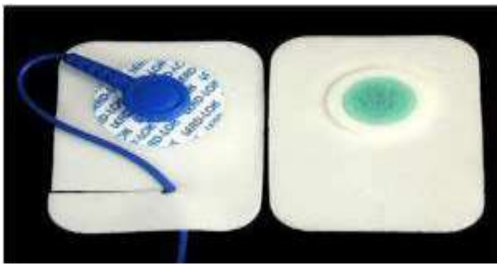


Figure 2.15. Flexible ECG electrode

2.4.2.4. Vacuum ECG Electrodes

It is an improved form of the metal plate electrode and does not require any adhesive or bonding straps, and is generally used to detect ECG signals over the chest (Picture 3.3). Since the skin-contacting surface of such an electrode is in the form of a ring (circle), even if the electrode is quite large, its impedance is large and therefore not suitable for use with amplifiers with small input impedance.

Figure 2.16. Vacuum ECG electrodes

2.4.2.5. Metal Plate Electrode

There is a metal layer in contact with the patient. Electrolyte paste is used to avoid artifacts in deep contact with this metallic plate and to obtain a clean signal.

While the electrodes on the chest surface are connected with a band aid, the electrodes using by attaching to the legs and arms are connected with a strap. Their impedance is small because their surface is large.

Figure 2.17. Metal plate electrode

2.4.2.6. Dry Electrodes

No gel is used between the electrode and the patient. In general, EEG signals are sequentially in a braided tape for sensing and are worn on the patient's head.

Figure 2.18. Dry electrode

2.4.3. Electrode Placements

An electrical circuit must be completed between the heart and the electrocardiograph in order to draw the ECG graph.

For this purpose, electrodes are located at certain places on the body surface and these electrodes are connected to the electrocardiograph via cables. The electrical circuits created in this way are called derivations (Soydan and Terek, 1992).

An ECG is created by measuring the electrical potential between different points of the body using a galvanometer. Leads I, II and III -measured over the arms and legs. Lead I from right arm to left arm, II. lead from right arm to left leg and III.

The lead is from the left arm to the left leg. From here, the imaginary point V is created on the heart, located in the middle of the chest. The other nine leads are arised from the potential between this point and the three limb leads and the six precordial leads (V1-6) (aVR, aVL, and aVF).

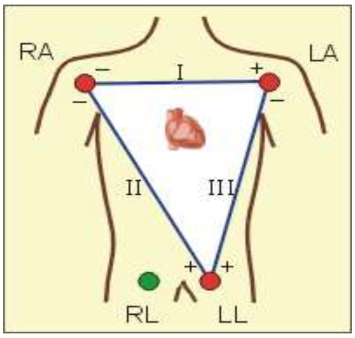


Figure 2.19. Lead I, II and III electrode placements

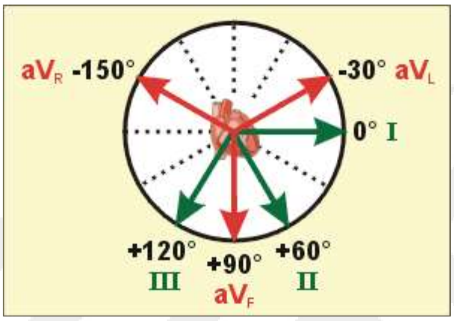


Figure 2.20. Electrode placements for aVR, aVL ve aVF derivations

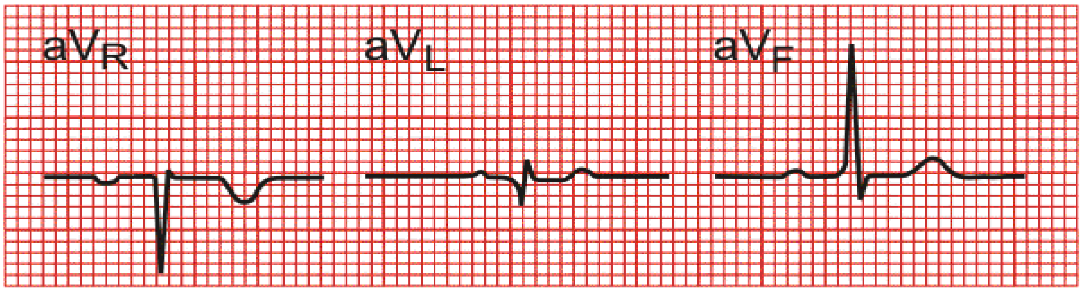


Figure 2.21. ECG images for aVR, aVL ve aVF derivations

Extremity Leads:

• I: The positive electrode is connected to the left arm, and the negative electrode is connected to the right arm.

• II: The positive electrode is attached to the left leg, and the negative electrode to the right arm.

• II: The positive electrode is attached to the left leg, and the negative electrode to the left arm.

• aVR: The positive electrode is attached to the right arm, the negative electrode to the other extremities.

Usually P, QRS and T are negative in this lead.

• aVL: The positive electrode is attached to the left arm and the negative electrode is attached to the other extremities.

• aVF: The positive electrode is attached to the left leg and the negative electrode is attached to the other extremities.

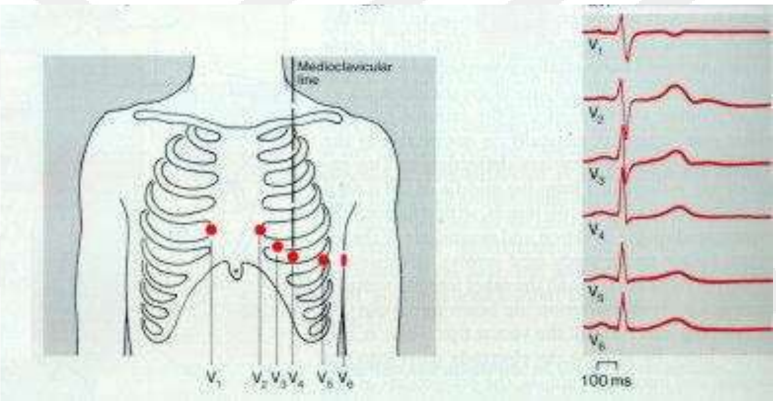


Figure 2.22. Leads and signals obtained (Alptekin, 2010).

2.4.4. Applications of ECG

ECG conduction and warning in the heart; It reflects whether the system is normal or not and the conduction disorders that occur due to myocardial damage. Conduction disorders of the atria create modifies in the P wave, and disorders of the ventricles cause changes in the QRS complex and T wave.

Purposes of ECG Imaging:

• Detects whether the heart is working normally or if there are some abnormal conditions (such as rhythm disturbance (arrhythmia), over or under heartbeat).

• Identifies the damages of sudden or previous heart attacks.

• Enables detection of conduction irregularities (such as cardiac obstruction).

• A imaging tool during exercise endurance testing for heart disease.

• It gives information about the physical condition of the heart.

• It can also identify some diseases not related to the heart (such as pulmonary embolism, hypothermia) (Kurban, 2006).

2.4.5. Previous studies on ECG

Recently, various studies have been conducted to view ECG signals.

1. Elena M. et al designed a smart cardiology imaging system using GPRS in their project called Cardiosmart. They preprocessed the ECG signal and sent only the problematic part, thus reducing the amount of data sent (Elena et al., 2002).

2. Dong J. and Zhu H. made a GPRS-based mobile ECG detector. They developed a mobile wearable wireless ECG detector with the Bluetooth protocol and provided the transmission of the ECG via GPRS (Dong and Zhu, 2004).

3. Thaddeus R.F. et al developed a portable, low-power, wireless ECG system (Thaddeus et al., 2004).

4. Yazıcı designed a mobile telemedicine (Telemedicine) system based on GPRS. A single-channel ECG and temperature measurement values with 0.5°C resolution were chosen as sample biomarkers. The information is sent to a specific IP address on the Internet via the GPRS modem of the personal mobile phone. The mobile device design was completed and sample data was written to the data base prepared on the PC over the GSM network and GPRS service (Yazıcı and Gulcur, 2005).

5. Proulx J. et al. designed an ECG monitoring system with Bluetooth (Proulx et al., 2006).

6. Kabalcı implemented a PC-based wireless ECG biotelemetry system in his thesis. He transmitted the ECG information he received from the body wirelessly with digital transmission techniques and transferred it to the computer environment (Kabalcı, 2006).

7. ZhuQ. and Wang M., wireless PDA-based ECG transmission system in their work, they have realized. They took the ECG signal with PDA and transmitted it to a remote medical ECG service via GPRS (Zhu and Wang, 2006).

8. Park C. and Chou P. have implemented an wearable, wireless, low-power ECG system in their study. They used a wearable, low-noise, capacitive sensor instead of the sticky electrode. Thus, the problems caused by the electrodes are eliminated. In order to be used in every country, the connection is provided via USB, Ethenet and Wi-Fi (Park and Chou, 2006).

9. Esme designed a remotely controlled heart device. The designed device is modular and portable. The transmission of ECG signals and other communication data can be via dial-up and the Internet, as well as via GSM modem. Unlike other studies in this field, it received feedback from the expert again via a computer network (Eşme, 2006).

10. Yang X. et al., in their study, took the ECG signal and processed it with GPRS. In their study, they sampled and analyzed the ECG signal, and when an abnormal situation was encountered in the ECG signal, they sent an alarm signal to the main center via the GPRS module (Xue et al., 2007).

11. Fidan and Güler designed a 4-channel biotelemetry device that enables the measurement of physiological data such as ECG, EMG, heart rate, respiratory rate, body temperature taken from the patient and transmitting various measurement results in parallel to a distance of 50-70 m (Fidan and Guler, 2007).

12. Zeybek built a portable ECG measuring device and transferred the ECG signals obtained with this device to a central computer wirelessly (RF), allowing the signals to be displayed on this computer (Zeybek, 2007).

13. Janckulik D. et al. studied the acquisition, processing and analysis of ECG data with web services in their project (Janckulik et al., 2008).

14. According to Can (2010), he tried to send the data he obtained to the phone by designing a low-cost device. With the Bluetooth module, which is a wireless technology, it transmits the ECG signals to the mobile phone and enables them to be displayed. By using the Bluetooth module, data flow is provided to other devices at a distance of 10 meters or to long distances with GSM operators (Can, 2010).

15. According to Bas (2011), he developed a design proposal for the monitoring of patients in his study. This system he developed consists of 2 parts. The first of these is the remote monitoring of the patients and the other is the monitoring of the patients in the hospital. The system proposed in the study has a three-layer block structure.

The first of these layers is the KVAA block, the second is the body area network server block, and the third is the medical server block (Bas, 2011).

16. Aktas et al. (2015) conducted a study on the transmission of physiological signals from patients using KVAAs and sent the ECG signals created in the wireless environment. In the application, a simulation was created using the OPNET Modeler program. Considering the results, it was concluded that the physiological signs obtained from the patients were successfully transmitted according to the quality of service parameters.

17. An ECG imaging system consisting of three different subsystems has been proposed (De Lucena et al., 2015). The first subsystem in this imaging system is used to read analog ECG signals. The second subsystem consists of a microcontroller and a bluetooth module and is used to convert ECG signals to digital and transmit them to a phone with Android operating system. The third subsystem is the phone itself, which is used to display ECG signals via appropriate graphs.

18. Affordable and effective ECG device that can integrate with mobile devices with Android operating system has been developed (Wu et al., 2016). In this system, ECG signals from non-invasive sensors are processed with the help of LabVIEW program and noises are removed. The mobile device works as a signal measurement and display system.

19. Babu et al. (2016) proposed an ECG imaging system consisting of three different subsystems. The first subsystem in this imaging system is used to read analog ECG signals. The second subsystem consists of a microcontroller and a bluetooth module and is used to convert ECG signals to digital and transmit them to a phone with Android operating system. The third subsystem is the phone itself, which is used to display ECG signals via appropriate graphs.

3. MATERIAL AND METHOD

The designed Holter ECG system includes two main parts as hardware and software. The studies carried out for these sections are described below. In this part, the detailed information is given about all the materials that were used in this study. The requirements and preparation stages of the project are explained.

3.1. Hardware of the System

In this section, the parts that make up the hardware of the system are explained.

The system should be light and portable, so a PCB circuit was used to make the system smaller. EasyEDA PCB design program was used for PCB Circuit design. EasyEDA is free to use. It is an internet and cloud based circuit design program. The program can work in harmony with all operating systems. Since it is internet and cloud-based, it can be used easily without downloading or installing any files on the computer. For these reasons, this program was used for PCB circuit design.

3.1.1. Data Perception Section

A sensor is required for the system to detect heart signals. AD8232 ECG sensor is used in this system.

3.1.1.1. AD8232

The AD8232 ECG sensor is a low cost module. It is used to measure the electrical activities created by the heart. The AD8232 can apply a bipolar high pass filter to eliminate motion artifacts and electrode half-cell potential.

This filter is tightly coupled with the instrumentation architecture of the amplifier to allow both large gain and high pass filtering in a single stage, thus saving space and cost. The AD 8232 is designed for the extraction and amplification of small signals in the presence of noisy background, the main sources of these sounds being muscle activities and motion artifacts produced by the patient's body.

The main task of the AD8232 chip is to extract, amplify and filter small signals of the electrical activity of the heart when a noisy situation occurs due to movement or remote electrode placement. To enhance common mode rejection of line frequencies and other unwanted interference in the system, the AD8232 includes an amplifier for driven lead applications for example a right leg driver (RLD).

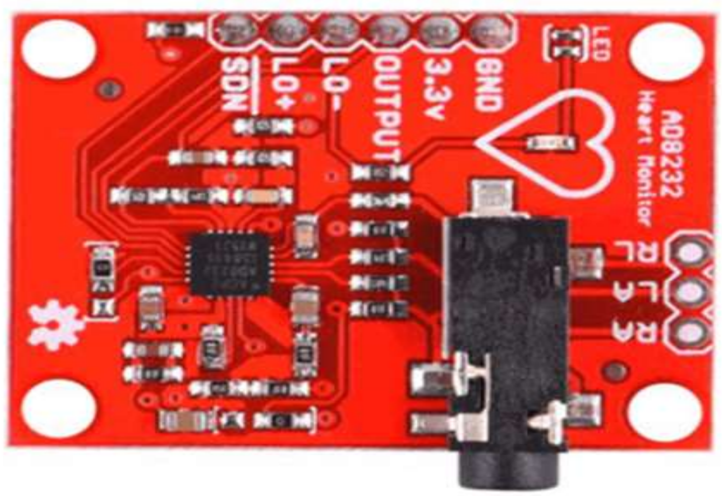


Figure 3.1. AD8232 ECG sensor

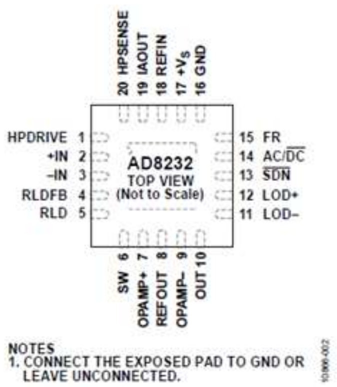


Figure 3.2. Pin Configuration of AD8232

The AD8232 contains out-of-wire detection. It has ac and dc sensing modes optimized for two- or three-electrode configurations, accordingly. The AD8232 has a gate capacitance of 15 pF and resistors of 10 kΩ on each input. This creates a low pass filter on each input that reduces the high frequency correction no adding external elements (Figure 3.3).

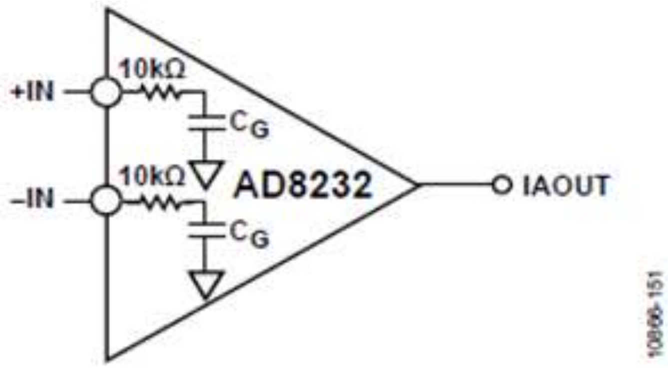


Figure 3.3. RFI filter without external capacitors

3.1.2. Data Processing Section

A processor is required to run the software in the designed system. In addition, the reporting of the obtained data will be uploaded to the cloud via UBIDOTS. For this reason, there must be a wifi network in the environment. The processor will run the algorithm we have determined, decide and send the results to the cloud via wifi. For this reason ESP32 is preferred.

3.1.2.1. ESP32

It is an abundant feature microcontroller with integrated Wi-Fi and Bluetooth connectivity for a wide various applications. Thanks to the Wi-Fi and Bluetooth on the ESP32, it has a useful structure for many IOT applications. ESP32 modules, which have a modular structure on the chip, as in ESP8266, make it very easy to design your own PCB board. Moreover, thanks to its low power consumption feature in sleep mode, it is also convenient for applications with low power consumption (Anonymous, 2022o).

Figure 3.4. ESP WROOM-32

Table 3.1. Specifications of ESP32 (Anonymous, 2022p).

Specifications	**ESP32**
MCU	Xtensa ® Single-Core 32-Bit LX6 600 DMIPS
8-2.11 b/g/n Wi-fi	Yes,HT40
Bluetooth	Bluetooth 4.2 and below
Typical Frequency	160 MHz
SRAM	512 kBytes
Flash	SPI Flash, up to 16 MBytes
Hardware / Software PWM	1/16 Channels
Touch Sensor	Yes
Temperature Sensor	Yes
Working Temperature	-40°C – 125°C

3.1.2.2. UG96 GSM Module

UG96 module is an included 3G wireless communication module, supports GSM/GPRS/EDGE and UMTS/HSDPA/HSUPA networks. It can also allow voice functionality) for your specific application. UG96 offers highest data rate of 7.2Mbps on downlink and 5.76Mbps on uplink in HSPA mode (Anonymous, 2022r).

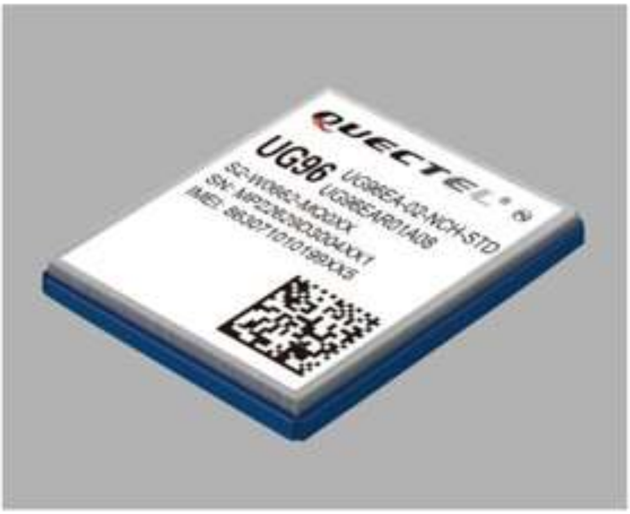


Figure 3.5. UG96 GSM Module

This allows integrators and developers to design their applications once and certainly take advantage of the global coverage and service flexibility afforded by the combination of the two most common cellular technologies worldwide. The UG96 can be preferred for high quality data and image transfer despite the harsh environments and quick time to market (Anonymous, 2022s).

3.1.3. Data Transfer And Storage

In the system, the ECG signals are detected by the AD8232 ECG sensor and then sent to the processor, namely the ESP32. In order for two devices to communicate, they must be on a certain protocol. A protocol is required to send data to the Ubidots server. In this project, the MQTT protocol was used to send the data. Data is stored in Ubidots.

3.1.3.1. MQTT Protocol

MQTT (Message Queuing Telemetry Transport) protocol is a machine-to-machine (M2M) message-based protocol widely used on the Internet.

It has gained acceptance in the Internet of Things (IoT) ecosystem with its light weight and low resource consumption. Almost all IoT cloud platforms support MQTT protocol to send and receive data from smart objects.

This protocol establishes a TCP/IP connection in a broadcast-subscriber structure, as contrary to HTTP, which is relied on a request-response structure. It works in Linux, Windows, Android, iOS, MacOS operating systems where TCP/IP protocol can be written.

The MQTT protocol will separate a client (publisher) broadcasting a message in publisher-subscriber structure to other clients receiving the message (subscribers). Also, MQTT is asynchronous protocol, which means it doesn't block the client while waiting for the message. Unlike the HTTP protocol, it is essentially a concurrent protocol.

The MQTT protocol is a right option for wireless networks that occasionally experience varying levels of latency due to bandwidth restrictions or unreliable connections. If the connection from a subscribed client to an agent is lost, the agent rebuffers messages and sends them to the subscriber when they are back online. In the event that the connection from the publisher client to the agent is lost without notice, the agent can close the connection and send a cached message to subscribers containing the publisher's instructions.

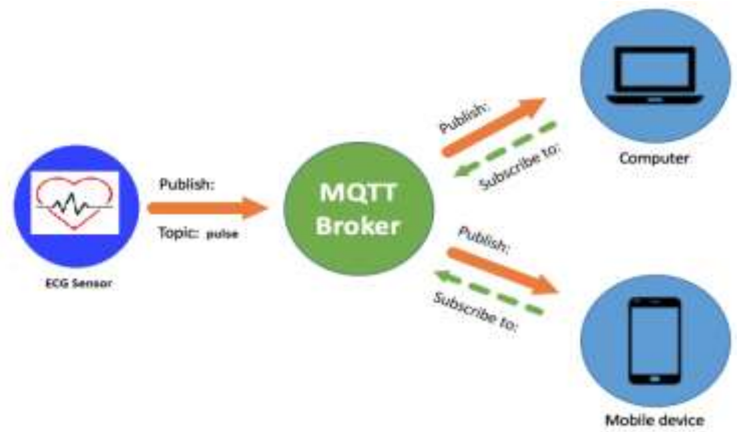


Figure 3.6. MQTT Architecture

Nowadays, Facebook uses MQTT for its messaging apps. It is preferred not only because it saves battery power during mobile phone to phone messaging but also because the protocol ensures efficient delivery of messages in milliseconds although inconsistent internet connections around the world.

Most main cloud service providers, including AWS, Google Cloud, IBM Bluemix, and Microsoft Azure, support MQTT, as do ThingOn IoT Platform.

3.1.3.2. Ubidots

Ubidots is an IoT Platform that empowers innovators and industries to prototype IoT projects and scale to production. The Ubidots platform can be used to send data to the cloud from any internet-enabled device. You can then form actions and alerts based on current-time data and reveal the value of the data through visual tools. Ubidots provides a REST API that allows reading and writing data to existing sources such as data sources, values, variables, events, and insights. The API supports both HTTP and HTTPS and an API Key is needed (Anonymous, 2022t).

Figure 3.7. Ubidots architecture

3.1.4. Data Display Section

3.1.4.1. OLED

The recent sort of light emitting diode (LED) family is an acronym that stands for "Organic Light Emitting Device" or "Organic Light Emitting Diode". It is a technology developed by Kodak company. Due to its low energy consumption in normal operation, its thin and light weight, its use in mobile phones has recently become widespread (Anonymous, 2022u)

OLED screen technology consumes much less energy as it distributes light through a single panel. It works with minimum energy consumption, especially when reflecting dark colors. For this reason, OLED technology is used in large device screens that consume a lot of power. Since its low energy consumption does not tire the device, it also offers a longer service life.

3.1.5. PCB

EASYEDA was used for PCB circuit design.

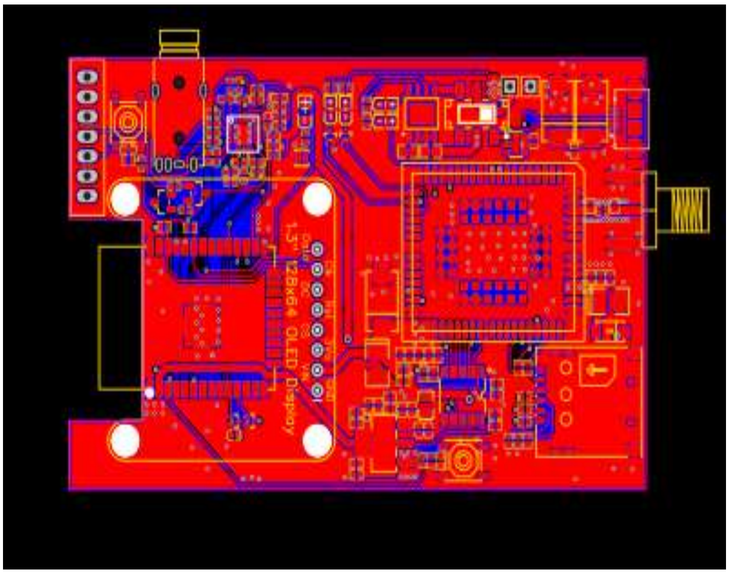


Figure 3.8. PCB design of holter ECG

The front and back of the PCB are as follows.

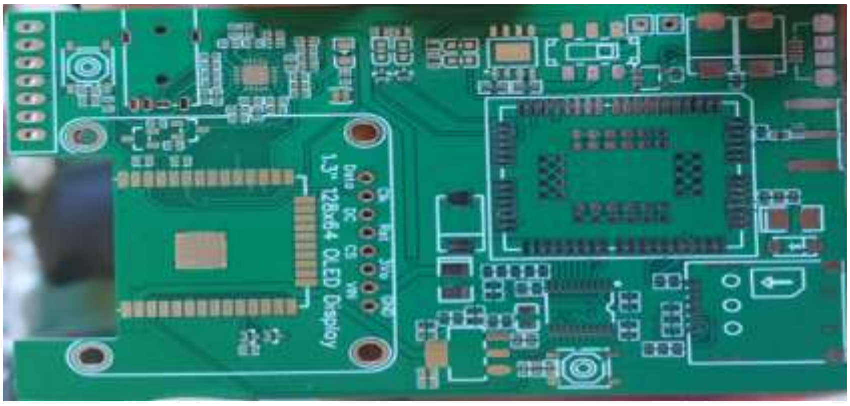


Figure 3.9. Front of the PCB

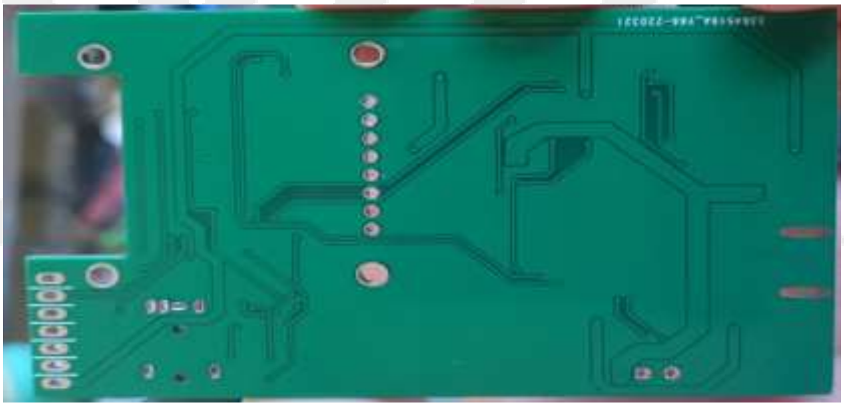


Figure 3.10. Back of the PCB

The circuit implemented on a PCB is shown in Figure 3.11.

Figure 3.11. Soldered PCB

3.2. Software of the System

Software development was done in C language. It was built on three main algorithms. In the first algorithm, the detected ECG signal is filtered and the heart rate is measured. In the second algorithm, if the heart rate is 40 bpm and below or 120 bpm and above for 10 seconds, the ECG signal is recorded and transferred to the cloud via Wifi. The third algorithm is the system, while the doctor or any number registered in the system is notified via SMS.

3.3. Operation of the System

In this thesis study, a system was designed for the follow-up of people with heart disease, especially patients who have or have had covid, or to provide accurate diagnosis and follow-up of people who may have heart disease.

The flow chart is given below.

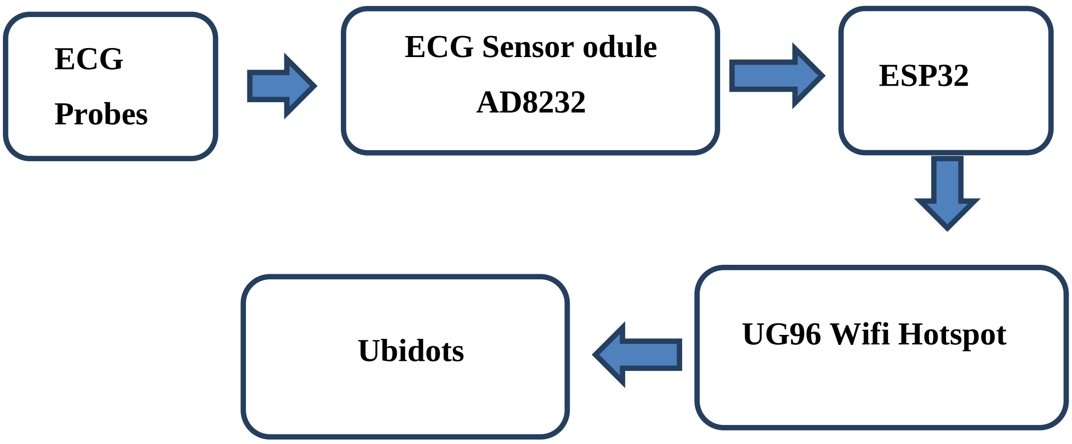


Figure 3.12. Flow diagram of the proposed system

In this thesis study, the ECG signal related to single-channel LA-RA (Lead I) electrode placement was taken from the state of 3 types of electrode placement in the Bipolar leads, which is one of the standard ECG leads. Accordingly, the points for placing the electrodes on the body are shown in Figure 3.13.

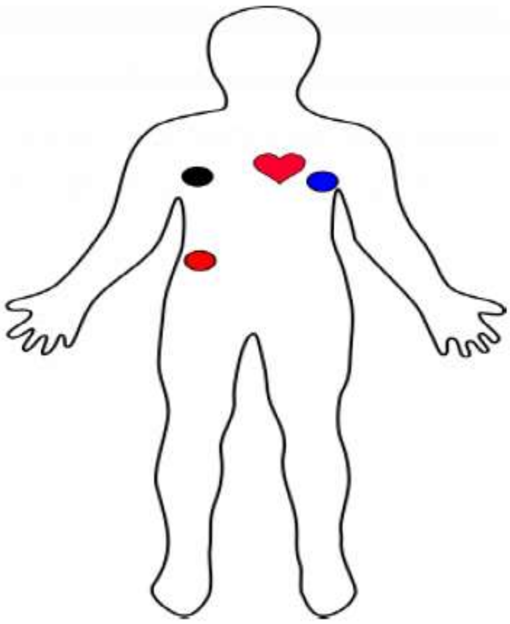


Figure 3.13. ECG electrodes placements

Ag-Cl electrodes were used in this thesis. The reason for choosing these electrodes is that they are disposable and hygienic, as well as being easy to supply, use and place.

Electrodes are attached to the patient to detect the ECG signal.

The signals received from these electrodes are processed with the AD8232 IC and converted into a meaningful analog signal. In this integrated, there are various filters and opamps with different gains for amplification. This integrated ECG automatically adjusts the signal level and automatically adjusts the output gains. With AD8232, it brings the ECG signal to a workable level without building a complex circuit.

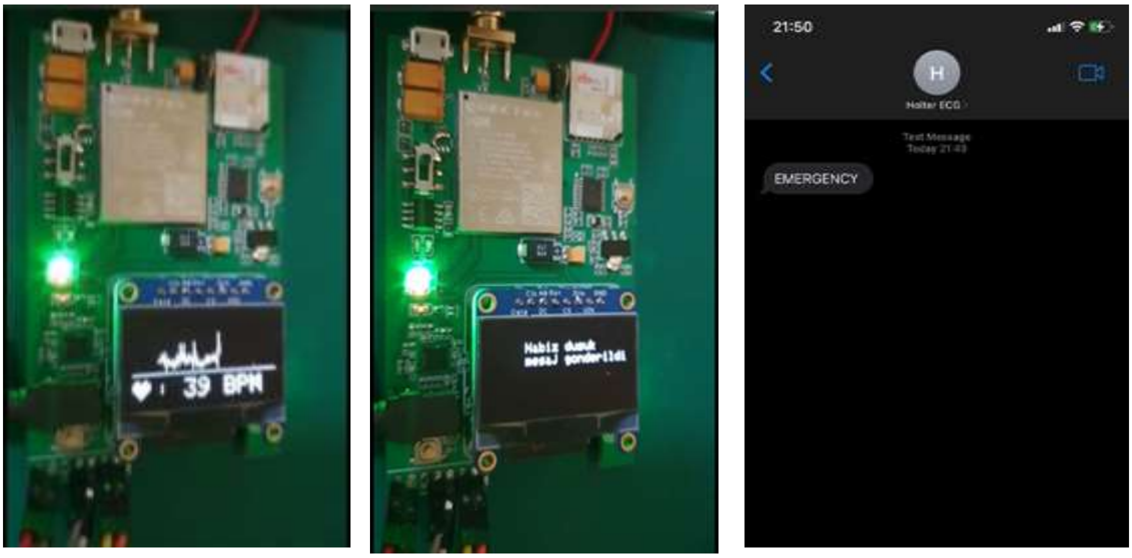
The signals coming out of the AD8232 IC are processed with ESP32.

Analog signals are first converted to digital signals, and the ECG signal is recorded and interpreted with different algorithms. ESP32 also includes Wifi and Bluetooth features. In this way, the processed data is sent to the targeted area via Wifi or Bluetooth. At the same time, the ECG signal is shown on the OLED screen. It is used to instantly send an SMS to the doctor in an emergency that may occur with the GSM module and to transmit the recorded ECG data of the patient to the doctor. But in this project, only SMS feature was used with GSM module. The patient's data was transferred to the Cloud via ESP32.

Since this project requires multidisciplinary work, the area belonging to the Ubidots company, which can be used as cloud-side ready and free, has been used. ECG information is transferred to Ubidots by using MQTT protocol with ESP32. ECG information can be followed live under necessary conditions via Ubidots. Different settings can be made by accessing the ECG device via Ubidots (Like mobile phone update).

The circuit works with a li-on battery. TP4056 charging IC is used to charge this battery. With this integrated Li-on battery is charged stably.

Figure 3.14. Operation of the system



a) b) c)

Figure 3.15. When heart rate is detected below 40 bpm a) screenshot b) screen alert c) forwarding SMS

a) b) c)

Figure 3.16. When heart rate is detected above 120 bpm a) screenshot b) screen alert c) forwarding SMS

4. RESULTS

After the PCB circuit was designed, the electrodes were placed on an individual according to a single-channel electrode layout. The signals detected through the electrodes are in the mV level and these signals are amplified with the AD8232. Noise and interference are filtered out for amplification. The detected data recorded the ECG data to the cloud when the patient's heartbeat was recorded at 120 bpm or above or 40 bpm and below for 10 seconds according to the software algorithm. At the same time, it sends an SMS to the number previously determined by the patient for emergencies. The designed system was tested on 3 individuals, 2 women and 1 man, over the age of 18. Gel is applied to the electrodes to minimize noise and get better results. Similar ECG charts were obtained in all three individuals. Results can be printed on special ECG paper and interpreted.

a)

b)

c)

Figure 4.1. ECG Chart of individuals a) woman b) man c) woman

5. DISCUSSION

In this thesis, saving data and sending SMS were carried out under the specified conditions. Considering the storage, battery and processing speed, the data is recorded only when the specified conditions are met, not 24 hours. The stored data is accessed via ubidots. Even if recording ECG data in abnormal heart rate values is sufficient for now, in some cases, days of follow-up may be required.

Saving data and sending SMS were carried out under the specified conditions. Considering the storage, battery and processing speed, the data is recorded only when the specified conditions are met, not 24 hours. The stored data is accessed via ubidots. The designed system was tested on 3 individuals, 2 women and 1 man, over the age of 18. Gel is applied to the electrodes to minimize noise and get better results. Similar ECG charts were obtained in all three individuals.

Considering the cost, dimension and pandemic conditions of existing ECG devices, the ECG is a low-cost, ergonomic device that will facilitate patient follow-up by doctors. Although the effect of the corona virus vaccine on the heart is still being researched, the widespread use of portable ECG devices will enable more patients to access ECG data. Many functions such as sending e-mail and GPRS can be added to the ECG device, which plays an important role in the diagnosis of many diseases.

6. CONCLUSION AND RECOMMENDATIONS

In this study, a 55x84 mm PCB electronic circuit was designed. The signals received from the patient through the electrodes were detected with the help of the AD8232 ECG sensor and transmitted to the ESP32, the processor of the system. Wi-Fi or Bluetooth is needed for the transfer of detected data. In this system, since the data will be transferred to an iCloud, the wifi feature of the UG96 GSM module was used. Data is transferred to UBIDOTs via wifi. At the same time, SMS is sent to the designated people in case of emergency.

After the PCB circuit was designed, the electrodes were placed on an individual according to a single-channel electrode layout. The signals detected through the electrodes are in the mV level and these signals are amplified with the AD8232. Noise and interference are filtered out for amplification. The detected data recorded the ECG data to the cloud when the patient's heartbeat was recorded at 120 bpm or above or 40 bpm and below for 10 seconds according to the software algorithm. At the same time, it sends an SMS to the number previously determined by the patient for emergencies.

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Considering the cost, dimension and pandemic conditions of existing ECG devices, the ECG is a low-cost, ergonomic device that will facilitate patient follow-up by doctors. Although the effect of the corona virus vaccine on the heart is still being researched, the widespread use of portable ECG devices will enable more patients to access ECG data. Many functions such as sending e-mail and GPRS can be added to the ECG device, which plays an important role in the diagnosis of many diseases.

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AYDIN ADNAN MENDERES UNIVERSITY

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SCIENTIFIC ETHICAL STATEMENT

I hereby declare that I composed all the information in my master's thesis entitled DEVELOPMENT OF HOLTER ECG within the framework of ethical behavior and academic rules, and that due references were provided and for all kinds of statements and information that do not belong to me in this study in accordance with the guide for writing the thesis. I declare that I accept all kinds of legal consequences when the opposite of what I have stated is revealed.

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